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Effect of different ankle- and knee-joint positions on gastrocnemius medialis fascicle length and EMG activity during isometric plantar flexion

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Abstract

The purpose of this study was to provide evidence on the fact that the observed decrease in EMG activity of the gastrocnemius medialis (GM) at pronounced knee flexed positions is not only due to GM insufficiency, by examining muscle fascicle lengths during maximal voluntary contractions at different positions. Twenty-two male long distance runners (body mass: 78.5 ± 6.7 kg, height: 183 ± 6 cm) participated in the study. The subjects performed isometric maximal voluntary plantar flexion contractions (MVC) of their left leg at six ankle–knee angle combinations. To examine the resultant ankle joint moments the kinematics of the left leg were recorded using a Vicon 624 system with 8 cameras operating at 120 Hz. The EMG activity of GM, gastrocnemius lateralis (GL), soleus (SOL) and tibialis anterior (TA) were measured using surface electromyography. Synchronously, fascicle length and pennation angle values of the GM were obtained at rest and at the plateau of the maximal plantar flexion using ultrasonography. The main findings were: (a) identifiable differences in fascicle length of the GM at rest do not necessarily imply that these differences would also exist during a maximal isometric plantar flexion contraction and (b) the EMG activity of the biarticular GM during the MVC decreased at a pronounced flexed knee-joint position (up to 110°) despite of no differences in GM fascicle length. It is suggested that the decrease in EMG activity of the GM at pronounced knee flexed positions is due to a critical force–length potential of all three muscles of the triceps surae.

Keywords: Plantar flexion; Muscle insufficiency; Muscle architecture; Force generation efficiency; Gastrocnemius; Human

1. Introduction

The force–length relationship of the sarcomere (Gordon et al., 1966), the thin filament (Walker and Schrodt, 1974) and the muscle fibre bundles (Zuurbier et al., 1995) is a fundamental mechanical property, which has been often used for the modelling of the whole muscle in models of the muscle–skeletal system (Zajac, 1989, 2002; Pandy et al., 1990; Anderson and Pandy, 2001; Bobbert, 2001). Especial attention has been paid to the muscle groups of the triceps surae and quadriceps femoris (Herzog et al., 1990, 1991a, b; Maganaris, 2001, 2003; Savelberg and Meijer, 2003), as these are very important muscles of the lower extremities for daily but also high performance activities. One of the main difficulties in estimating the force–length relationship of a muscle in vivo is the variation of the voluntary activation during changes in muscle length (Vander Linden et al., 1991; Hasler et al., 1994; Suter and Herzog, 1997; Tamaki et al., 1997; Miaki et al., 1999; Pinniger et al., 2000; Kennedy and Cresswell, 2001; Onishi et al., 2002; Babault et al., 2003). Whereas at short muscle lengths some studies have reported a decrease in EMG activity (Cresswell et al., 1995; Tamaki et al., 1997; Miaki et al., 1999) and discharge rates of

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motor units (Kennedy and Cresswell, 2001), others found the EMG activity (Vander Linden et al., 1991; Hasler et al., 1994; Babault et al., 2003) and the voluntary activation (Suter and Herzog, 1997) to increase.

Nevertheless, the reports from the literature regarding the gastrocnemius medialis (GM) during maximal isometric plantar flexion are in agreement and it is generally accepted that there is a decrease in the activation of the GM at pronounced knee flexion positions, i.e. short muscle lengths (Cresswell et al., 1995; Miaki et al., 1999; Pinniger et al., 2000). The reported mechanism underlying the decrease in muscle activation at short muscle lengths is the active insufficiency of the GM muscle, because the muscle reaches a critical shortened length at which, due to the force–length relationship, the torque output cannot be increased even if the muscle is fully activated (Herzog, 2000; Kennedy and Cresswell, 2001). The force potential of the muscle due to the force–length relationship, which is the reason for the muscle insufficiency, is dependent on the fascicle length. During a contraction, despite of a constant length of the muscle–tendon unit, the fascicle length of a muscle does not remain constant because of the non-rigidity of the tendon and aponeurosis (Fukunaga et al., 1997a, b). Furthermore the changes in pennation angle during the contraction influence the force transmission to the tendon and contribute to muscle length changes (Zuurbier and Huijing, 1993).

The soleus (SOL), GM and gastrocnemius lateralis (GL), attach to the same tendon (Achilles tendon). During maximal plantar flexion efforts all three muscles are contributing to the torque output and so to the amount of tendon elongation (Maganaris and Paul, 2000; Magnusson et al., 2001; Rosager et al., 2002). This means that a higher tendon force would increase the elongation of the Achilles tendon as well as the shortening of the fascicle length of all three muscles (SOL, GM and GL). At positions where the knee is more extended and the ankle dorsal flexed, the exerted plantar flexion moment is higher (Herzog et al., 1991b). Due to the non-rigidity of the muscle–tendon unit, this higher moment will lead to a higher elongation of the triceps surae tendon and aponeurosis (Maganaris and Paul, 2000). A higher elongation of the triceps surae tendon and aponeurosis during maximal voluntary contraction would decrease the force potential due to the force–length relationship of all three muscles (SOL, GM, GL) because in vivo they work on the ascending limb of the force–length relationship due to the anatomical constrains of the ankle- and knee-joints (Herzog et al., 1991b; Maganaris, 2001, 2003). Therefore it can be hypothesised that the EMG activity of the GM during isometric maximal plantar flexion contractions is regulated in order to positively influence the force–length relationship of all three muscles together.

However, to our knowledge, there is no study reporting a decrease in the activation of the GM during maximal plantar flexion, simultaneously examining the fascicle length during the contraction. The existing studies (Cresswell et al., 1995; Tamaki et al., 1997; Miaki et al., 1999; Kennedy and Cresswell, 2001) estimated the fascicle length of the GM from the ankle- and knee-joint angles. This estimation may be accurate for the inactive GM (at rest) but not at the steady state of a maximal isometric contraction. As an example Kawakami et al. (1998, 2000) reported similar fascicle lengths of the GM during maximal plantar flexion whilst having different ankle- and knee-joint combinations despite of different fascicle lengths at rest. Therefore, it is not possible to conclude that at a constant ankle angle a pronounced knee flexed position would cause a shorter fascicle length at the steady state of a maximal isometric contraction. The possibility of having a decrease in the GM EMG activity in a pronounced knee flexed position without having shorter muscle fascicles lengths than at more extended knee-joint positions has not yet been examined in the literature. The examination of the above is important because if it proves true, evidence would exist confirming that the observed reduction in EMG activity of the GM cannot be explained solely due to its insufficiency.

The purpose of this study was to examine the possibility of having a decrease in the GM EMG activity in a pronounced knee flexed position without having shorter muscle fascicles lengths than at more extended knee-joint positions and so provide evidence that the decrease in the EMG activity is not only due to GM insufficiency.

2. Methods

2.1. Measurement of the EMG activity and the ankle joint moment

Twenty-two male long distance runners (body mass: 78.5 ± 6.7 kg, height: 183 ± 6 cm) participated in the study. Subjects were instructed about the experimental protocol and their informed consent to participate was obtained. The subjects performed isometric maximal voluntary plantar flexion contractions (MVC) of their left leg at six ankle–knee angle combinations (Table 1). The order of plantar flexion contractions at the six positions was randomised. The subjects had a brake of at least 3 min between the maximal isometric contractions. Bipolar EMG leadoffs, with pre-amplification (bandwidth 10–500 Hz), were used to record muscle activity. Adhesive surface electrodes (Ag/Ag Cl) with an electrolytic gel interface and a pickup surface of 0.8 cm^2 (blue sensor—Medicotest Denmark) were positioned above the mid-point of the muscle belly. The